

# Self-Reconfigurable Robots & Digital Hormones

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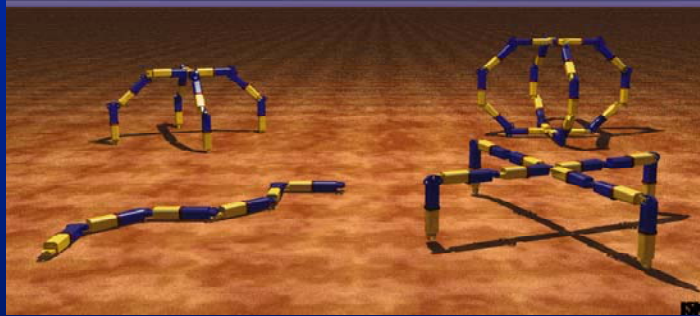
<http://www.isi.edu/conro>

## Outline

- What is metamorphic (self-reconfigurable) robots?
- Why is it interesting and challenging?
- Autonomous modules for self-reconfiguration
- *Digital Hormones* for software control
- Applications to space exploration

## Self-Reconfigurable Robots

### Spider Link Models



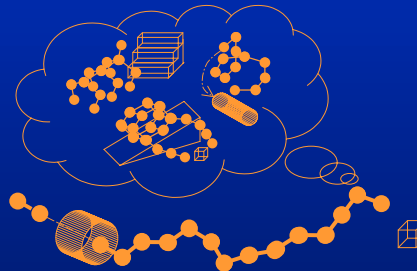
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## CONRO Robots

- Research Objectives
  - Morph to deal with diverse applications
    - Snake for tight space
    - Track for fast moving
    - Multi-arms for assembly
- Technical Requirements
  - Self-reconfigurable
  - Autonomous
  - Miniature
  - Adaptive in shape and behavior
  - Self-repair and fault-tolerance



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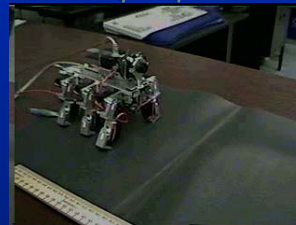
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## The First Generation (1998)



*Multiple gaits*



*Multiple shapes*



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## The Second Generation (99-01)



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## Online Configuration Behaviors

- Capable of reconfiguration during operation
- No need to shutdown the system
- Enable on-line repair in the future
- First robot in the history that can perform this!



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## Challenges in Hardware

- Autonomous and self-sufficient modules
- Integrated packaging for components
- Power efficiency and management
- Actuators and sensors
- Communications
- Docking mechanisms
- Extensibility for sensors and manipulators

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## Challenges in Control

- Distributed
  - Autonomous modules must be coordinated
- Dynamic
  - Network and configuration topology changes
- Asynchronous
  - Communication with no real-time clocks, global or local
- Scalable
  - Weak local actions vs. grand global effects
- Fault-tolerant
- Miniature and self-sufficient

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## Related Work

- Self-Reconfigurable robots and systems
  - Self-organization and pattern formation (Turing 53)
  - Cebots (Fukuda Nakagawa '90, JSME)
  - Polybots (Yim 94)
  - Reconfiguration metrics (Chirikijan 98)
  - 3D reconfigurable structures (Murata '98)
  - Molecules (Kotay&Rus '98)
  - Feather formation (Chuong '98)
  - Self-Transforming robots (Dubowsky 2000)
- Control approaches
  - Centralized control tables & open-loop with global clocks (Yim94)
  - Multi-agent approaches (Xerox PARC, 2000)
  - Finite State Machine, Locomotion by Reconfiguration (Rus 2000)
  - Decentralized and autonomous, but non-reconfigurable (Mori84)
  - Homeostatic control for resource allocation (Arkin88)

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## Digital Hormones

- Content-based messages
  - No addresses nor identifiers
  - Have finite life time
  - Trigger different actions at different sites
- Floating in a global medium
  - Propagated, not broadcast
  - Internal, not external (pheromones)
- Total autonomy for individual sites
- Hormones can modify module behaviors (RNA)

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## Types of Digital Hormones

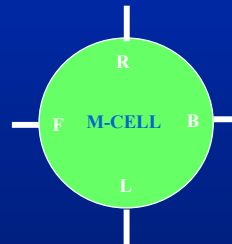
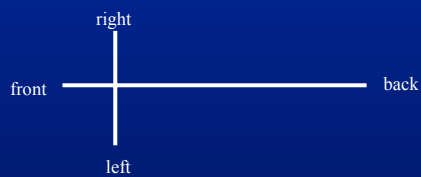
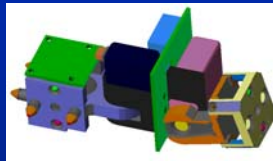
- Two main types
  - **Action-triggering** Hormone (AH)
    - (AH, Task, Action, Data, TimeToLive)
  - **Synchronization** Hormone (SH)
    - (SH, Action, AHSet, Data, TimeToLive)
- Other types
  - **Conflict-resolution** Hormones (CH)

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# Mechanical Cells (M-Cell)



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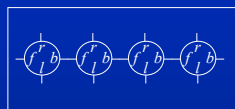
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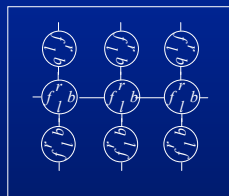
# M-Cell Organizations



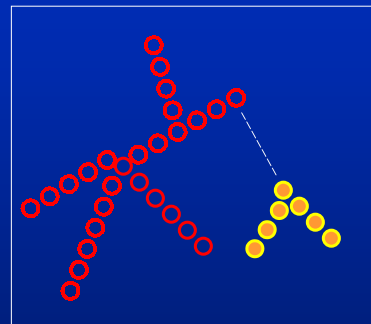
A module



A Snake



A 6-leg insect



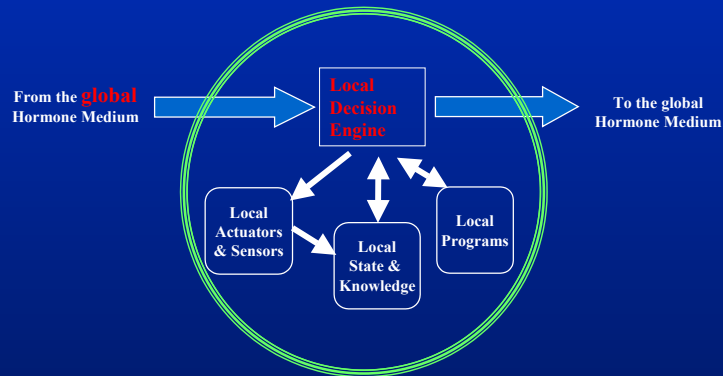
Communication between two separate creatures

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## M-Cell Internal Structure



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## The Uses of Digital Hormones

- Communication in dynamic network
- Cooperation among distributed autonomous modules
  - Locomotion
  - Reconfiguration
  - Synchronization
  - Global effects by weak local actions
  - Conflict resolution (multi hormone management)
  - Navigation
- Adaptation and self-repairing

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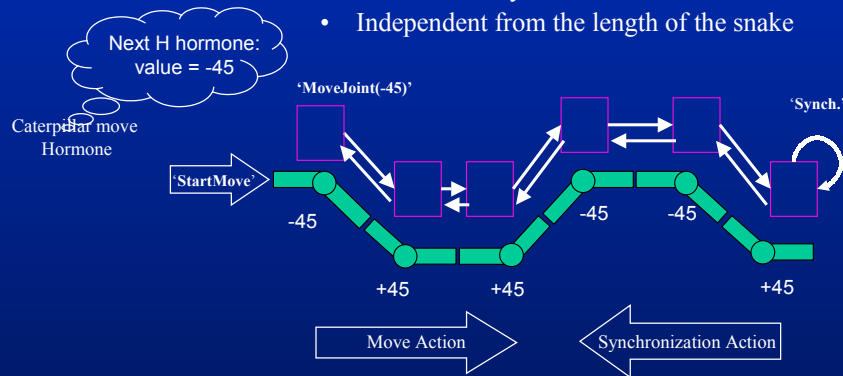
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## Hormones for Caterpillar Move

- A simple one-pass hormone from head to tail
- Controls and synchronizes all motor actions
- Independent from the length of the snake



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## Locomotion Behaviors

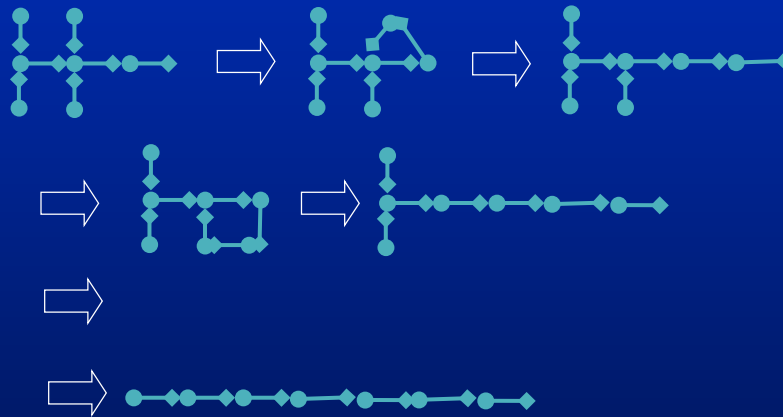


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## Reconfigure Insect → Snake



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## Hormone Activities

| Active hormones   | Actions   |
|---|---|
| LTS   | Start the reconfiguration                                   |
| RCT <sub>1</sub> , RCT <sub>2</sub> , RCT <sub>3</sub> , RCT <sub>4</sub> | Legs are activated  |
| TAR, RCT <sub>2</sub> , RCT <sub>3</sub> , RCT <sub>4</sub>               | The tail inhabits RCT, and leg1 determines RCT <sub>1</sub> |
| ALT, RCT <sub>2</sub> , RCT <sub>3</sub> , RCT <sub>4</sub>               | The tail assimilates leg1 and then accepts new RCT          |
| TAR, RCT <sub>2</sub> , RCT <sub>4</sub>                                  | The tail inhabits RCT, and leg3 determines RCT <sub>3</sub> |
| ALT, RCT <sub>2</sub> , RCT <sub>4</sub>                                  | The tail assimilates leg3 and then accepts new RCT          |
| TAR, RCT <sub>2</sub>   | The tail inhabits RCT, and leg4 determines RCT <sub>4</sub> |
| ALT, RCT <sub>2</sub>   | The tail assimilates leg4 and then accepts new RCT          |
| TAR   | The tail inhabits RCT, and leg2 determines RCT <sub>2</sub> |
| ALT   | The tail assimilates leg2 and then accepts new RCT          |
| ∅   | End the reconfiguration                                     |

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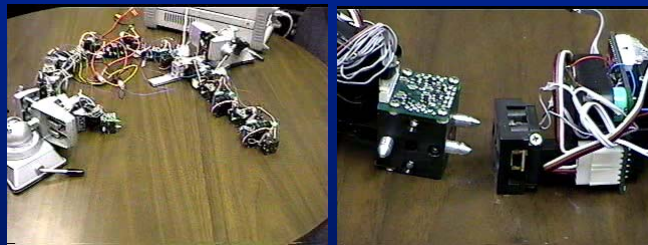
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## Docking Demonstration



Prototype 1:  
centralized control



Prototype 2:  
distributed  
control using  
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## Task Driven Reconfiguration

- Modules are **typed** by their connections
  - There are 32 types of CONRO modules
- A configuration is a **graph**
  - Nodes = typed modules
  - Edges = neighboring relationships
- Configuration **space** is
  - States = configuration graphs
  - Operators = “add or delete one edge”
- Configuration **evaluation** function
  - $F(\text{configuration properties, environmental properties})=[0,1]$

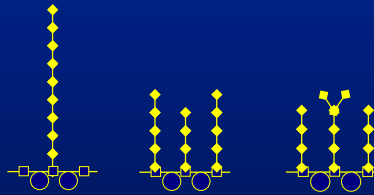
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## Space Application (I)

- There exists applications where SRR are necessary
- Payload management (joint work with NASA JPL)
  - Send one self-reconfigurable robot to accomplish a variety of tasks, such as building, digging, transportation, and exploration
- Metamorphic Machinery:



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## Space Application (II)

- Relative Human/Robot Roles (joint work with NASA Ames)
- Lego-like robots for future astronauts
  - toolkit of robotic parts snapped together into appropriate shapes and size
    - with needed end-effectors
    - specialized locomotion strategies
- Will enable two critical breakthroughs
  - The system of interfaces among components
  - The planning ability to find needed configuration and execute the series of motions and module transfers that will accomplish the task

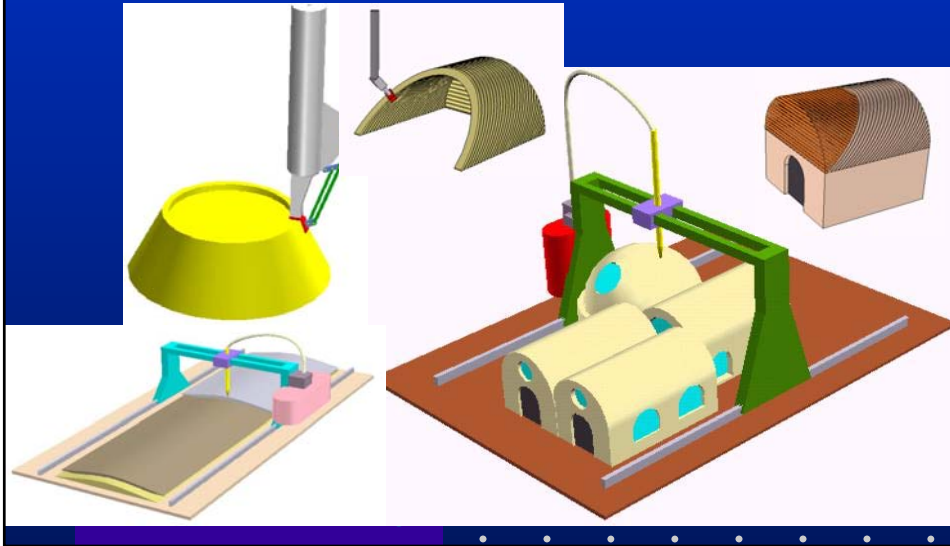
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## Space Application (III)

### Contour Crafting – An Additive Fabrication Process (Berok Khoshnevis)



## Other Applications

- Space station maintenance
  - Similar to submarine maintenance
- Energy saving and mass saving
- Robust automation for
  - Exploration, drilling, mining, transportation, assembling, and construction



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## Future Work

- Environment/task Driven Reconfiguration
  - Interface with human operators
- Robust/Economic Modules for Deployment
  - Fast and reliable hardware/software for docking
  - Resource management for time-sharing activities
- More Diverse Capabilities
  - Navigation
  - Autonomous reconfiguration
  - Sensor-driven applications
- Diverse Environments
  - Space, underwater, factories

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## Conclusions

- Self-reconfigurable robots pose many scientific research topics
  - Interdisciplinary between CS, AI, Biology, ME, MEMS, ...
  - Must integrate many leading technologies
- Self-reconfigurable robots are very promising
  - Space exploration presents applications that SRR is necessary
  - Has potential to be applied to many applications
  - Building platforms for future science capabilities

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